A picture worth a thousand words

Using new character-generating tube and a crt, photocomposition system for printing is capable of setting type at speeds of 1,000 to 10,000 characters per second while making up the page in the same process

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Within the next three months, the fastest photocomposing system ever devised will be installed at the world's largest printing plant, the U.S. Government Printing Office (GPO) in Washington. Combining phototypesetting and page composition by a computer, the system is capable of setting type electronically for an entire page of this magazine in about five seconds via a new character-generating tube and a specially designed cathode-ray tube.

Called Linotron, it can set 1,000 characters a second with the clarity required for quality printing [see "Quality in electronically set type," page 118]. Pages for proofreading before final page copy is set can be composed at several thousand characters a second; speeds up to 10,000 characters a second can be achieved for typewritten-like pages.

The system was a joint undertaking by the Mergenthaler Linotype Corp., a division of the Eltra Corp., and the Columbia Broadcasting System Inc.'s CBS Laboratories division. Mergenthaler is responsible for the over-all system management, programing, and installation. The photocomposing equipment was developed by CBS. Its key elements are the character-generating tube[1] and crt, described in detail in the article on page 122. Development began in 1962. More than $6 million has been invested to date.

Unlike conventional linecasting machines — standard in the printing industry — and phototypesetters, the Linotron does not require mechanical motion or motion of film to set a full page of type. It sets the page, character by character, and is not restricted to line-at-a-time composition. Letters and numbers from three type fonts, or styles, are exposed on film at locations selected by a computer. If another type should be required, characters from this font can be exposed at spaces left open for them. This eliminates constant shifting back and forth of different fonts. Ruled lines, graphic material, and other information can also be put on the page.

This technique gives the editor greater freedom in selecting type style, page size, and page format without sacrificing the speed inherent to the system. Line-at-a-time systems require mechanical motion and are slower than electronic systems. The films exposed by the Linotron's output, the crt display, can be automatically processed off-line and can be used to prepare plates for offset, letterpress or gravure printing.

Applications of the Linotron system in computer peripheral equipment and automatic drafting systems are also feasible. For example, information could be selected from "fonts" that are actually electro-optical read-only memories. These memories could be used by a computer as fast-access lookup tables or data files. The scanning systems employed in the Linotron permit the equivalent of 5,750,000 binary bits of data to be stored in a volume of only 2 cubic inches, accessible in 100 microseconds. The

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readout rate would be 5 megahertz.

The crt subsystem could also be used as an extremely accurate flying-spot scanner for pattern recognition and filmed data retrieval. In such applications, a negative would replace the film and the crt beam would be modulated by the information on the negative and detected by a photomultiplier.

In one of its operating modes—the one used to start a line at a selected point on a page—the Linotron functions as an X-Y plotter under control of a computer-prepared program. It can draw lines at the sweep speed of a crt, or by making points at a rate of 10,000 a second. As a plotter, it could be used, for example, to prepare integrated circuit metalization masks under computer control.

Generation to display

The Linotron system looks at an optical analog of a type font, generates video signals corresponding to the characters and their lateral position with respect to adjacent characters in line. It then displays the characters on a crt at selected locations within a page format. As each character is displayed, it is exposed on the film. Linotron, system diagram on page 115, resembles a special-purpose, closed-circuit television scanner and kinescope film recorder.

Instructions for selecting and placing characters, and other typographical effects, are recorded digitally on magnetic tape. Another system, under development for the Air Force Logistics Command, will have a video tape input as well, enabling the system to compose artwork and photographs on the page of type.

At the GPO, preparation of the magnetic tape will be handled by a specially programed IBM-360/50 computer. Material to be printed will be fed into the computer from data banks updated by punched cards. The computer will do such typesetting chores as spacing out the lines and hyphenating words. The tape will also contain instructions for page makeup, paragraph indenting, type font changes, and so on.

In the Linotron, the tape is read out in data blocks into buffer core storage. A dual buffer is used so that while one is being loaded from the tape, the other is providing instructions to the rest of the system.

Control logic decodes the tape information into a variety of signals which determine such printout properties as the character to be generated, its position, size, and type style.

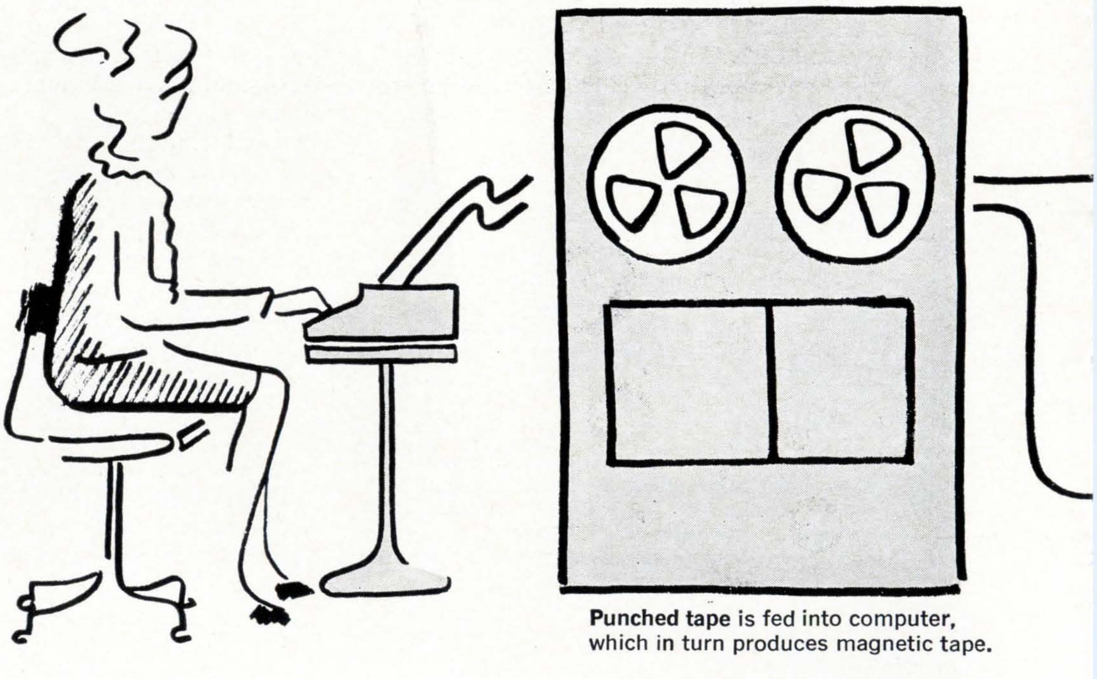
Special precedence codes enable the system to specify the complex requirements of the graphic characters. The logic also controls auxiliary system functions such as determining the length of film on which the display from the crt is to be printed and whether a standard information overlay is to be projected onto the film.

After the page is composed on the crt, the display is optically enlarged 2.3 times to a maximum of 8¼

Words, words, words

Why does the Government Printing Office require a high-speed photocomposing system? The answer can best be told in numbers.

Last year alone the GPO set 110 million lines of type (calling for more than 3.2 billion characters). It processes on the average 1,000 printing orders per day, ranging from Congressional stationery to the 16-volume U.S. legal code. Through the Superintendent of Documents, more than 27,000 different titles are available for sale to the public. Better than half of this printing is done by the GPO; commercial printers do the balance under contract.



Text and instructions for the system are produced by typist on punched tape

Punched tape is fed into computer, which in turn produces magnetic tape.

x 10½ inches before the film is exposed. This is the largest page size generally used by the GPO. Larger pages can be composed by programing the information so a complete page is represented by placing film pages side by side.

Part of the attraction of the Linotron's full-page composition is that the computer preparing the text can call for a character to be located anywhere on the page. In a conventional phototypesetter, the computer would have to complete one line before going on to the next, or rewind the film. This is both bothersome and time consuming, particularly with multicolumn formats. The computer would have to complete lines with contributions from each of the columns rather than follow the natural flow along a single column.

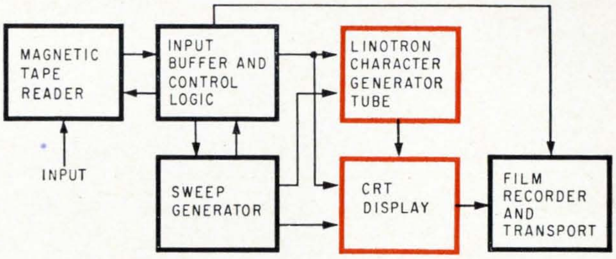
Character store

It was recognized early in the development of the system that character generation required a special type of read-only memory. Information retrieved from this store is used but not changed.

Many kinds of read-only character generators have been described over the past 20 years.[2, 3, 4] Although some had been tailored for high-speed writing, none had to generate characters that would photograph with the high resolution required in this photocomposing system.

Clearly, the best character source for the Linotron system is a photograph. It has high resolution, costs little and takes up little space. In addition, the original artwork prepared by the type designers can be used directly, and large groups of characters can be changed quickly.

The basic element of the photographic store in the character-generating tube is a grid printed on a glass plate, top of page 117. It stores a 16 x 16 array of 256 characters; a single array contains the equivalent of three type fonts. The plate is mounted in a precision stainless steel frame. Access time to any character is of the order of a few nanoseconds. Information transfer from the grid occurs at a 5 Mhz rate after a 100-microsecond servopositioning cycle.



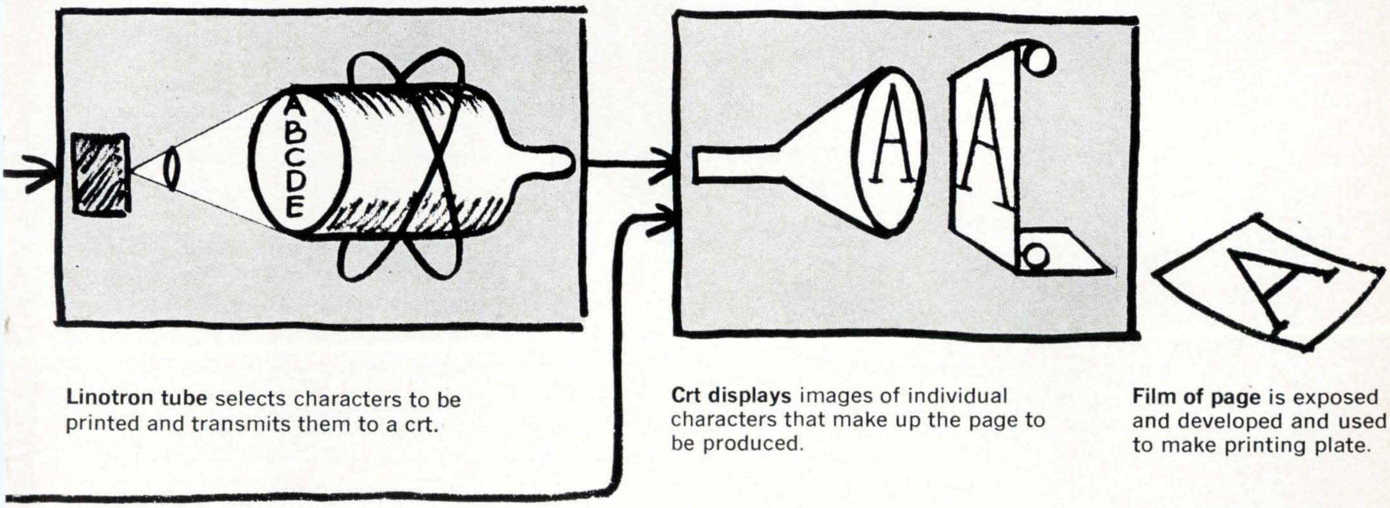
Linotron photocomposing system accepts instructions on magnetic tape, generates electronic analogs of characters in the Linotron tube and displays 1,000 characters per second on the cathode-ray tube. Printing plate is made from photograph taken of crt faceplate.

A character, shown in detail on page 119, appears on the glass plate with a reference mark at the lower left. Information bits that follow the mark store data related to the character's position with respect to adjacent characters. This information isn't on the magnetic tape.

The 256 characters in a grid can be reproduced in eight sizes, sufficient for most printing jobs. When a fourth font is required, a grid changer holding four separate grid plates is used. The changer can switch any one of the plates into the system in a half second. Thus, 8,192 characters in different sizes and fonts are actually available to be reproduced.

Linotron tube

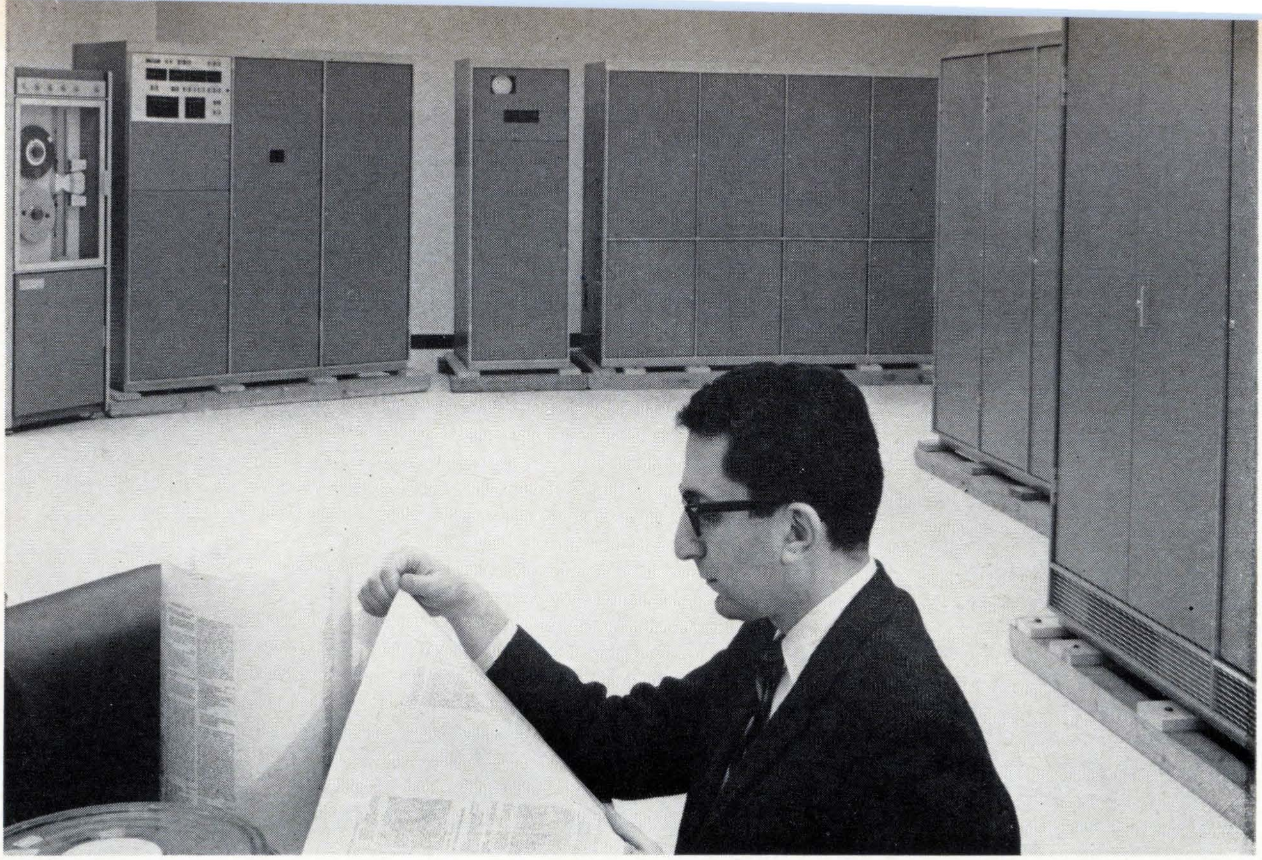
The character grid is illuminated by a mercury arc lamp and its image is projected onto the Linotron tube's photosensitive faceplate. Each character image is converted into a video signal in the



Linotron tube selects characters to be printed and transmits them to a crt.

Crt displays images of individual characters that make up the page to be produced.

Film of page is exposed and developed and used to make printing plate.



Engineer reads pages with several different type sizes printed from plates prepared from film. System cabinets are in the background.

tube. One signal at a time is amplified in the electron multiplier section, then transmitted to the crt.

The video output is an instantaneous and accurate analog of the character's shape. There are none of the settling time or hysteresis problems associated with flying-spot scanners. Furthermore, there is no time constant analogous to the decay in crt phosphors to limit the video bandwidth, which is 5 megahertz.

Helmholtz coils are used in the Linotron tube to produce uniform magnetic fields for focusing and deflection. High-power deflection amplifiers supply the sweep currents. The smaller the character, the higher the deflection frequency, which reaches 125 kilohertz.

After a character is selected by the input buffer, the video output from the Linotron tube is connected to a servosystem, shown in the block diagram, page 119. The servo drives the deflection amplifiers of the Linotron and locks the scan to the coordinates of the reference mark on the character grid. The techniques used are similar to those in star-tracking systems.

The servosystem aligns each character scan to the character and corrects errors introduced by variations in positioning the grid changer, manufacturing tolerances in fabricating the character grids, drift in the sweep generators, and deflection amplifiers. Alignment accuracy is about 0.0001 inch.

Cathode-ray tube

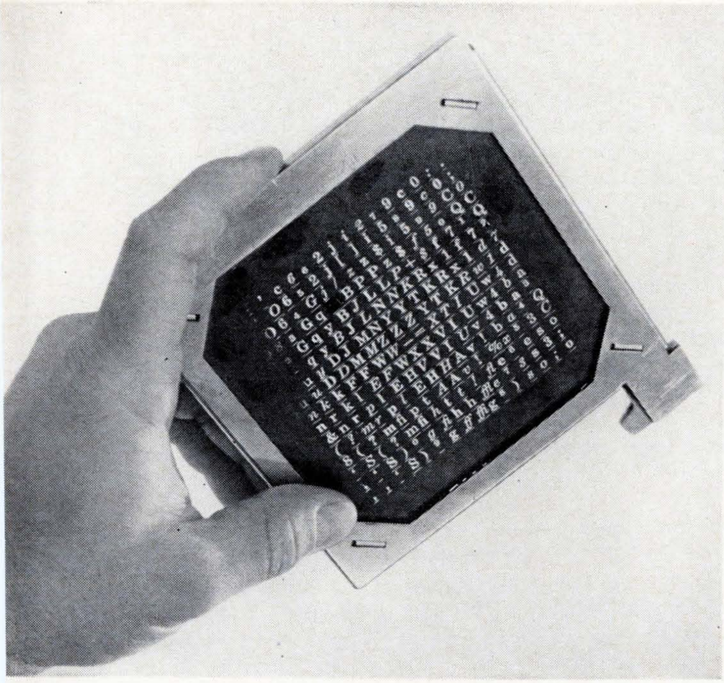
A 7-inch crt, type CL1242 P24, with an additional optical magnification of 2.3, exposes standard phototypesetting film. The useful phosphor area of the tube actually has about a 6-inch diameter. Spot size is typically less than 1.5 mils at beam currents of 20 microamps and accelerating potentials of 30 kilovolts. Deflection defocusing introduced by the 20° deflection system is kept below 10%.

The crt uses a dual magnetic deflection system, shown in the block diagram on page 120. A major deflection yoke, driven from a precision digital-to-analog converter, positions the character and a minor deflection yoke writes it out. Deflection amplifiers similar to those used in the character generator drive the minor deflection yoke.

Digital-to-analog conversion

Digital-to-analog converters take the digitally coded position address supplied by the control logic and place the 1.5-mil diameter crt spot at the character starting point on the crt. Both the horizontal and vertical converters are driven by 5-digit binary coded decimal inputs. The least significant digits represent a deflection of 1/18th of a point (a point is a measuring unit for type) or 0.0007687 inches on the film.

Groups of weighted current sources controlled by current switches make up the digital-to-analog converters. Their long-term stability is high, 0.01%. They are modulated by a signal that is a function of the deflection current. The deflection current is fed back into the converters and modulates their output as a function of the crt spot position. The modulation is controlled by a function generator that corrects the signal to obtain a differential linearity distortion of only 0.01%.



Character grid is a photographic store of 256 type characters. Linotron tube selects one character at a time which is transmitted as a video signal for projection onto crt display.

With the suitably shaped deflection current signal, the spot is placed within 0.02% of its required position. Linearity correction is possible because precise pincushion correction makes the crt's deflection sensitivity independent of axes.

Sweep generation

The sweep generator in the Linotron system synchronizes the character generator with the crt display. The system has:

▪ Constant video bandwidth of about 5 Mhz, independent of character size for a given resolution at the film plane.

▪ Constant energy density at the film independent of the type size.

▪ Typesetting speed constant for a given area of composition; if type is not required on some areas of a page, the page is set more rapidly.

▪ Asynchronous operation with small characters printed at a high speed and larger characters printed at slower speed.

The number of scan lines on the output film is 835 per inch. This is large enough to take advantage of the 1.5-mil spot size available from the crt, since with a conservative Kell factor (a measure of the overlap of scan lines) of 0.6, the resolution is about 500 lines per inch. Very high contrast prints—up to a film density factor of 3—are obtained with a spot velocity of 13,000 inches per second.

The largest size character to be printed in the GPO's Linotron is 18 points—up to ¼ inch high. (Larger characters can be produced by modifying the circuitry.) The smallest will be a 5-point character.

As the character gets smaller, the period of time in which it's swept out on the crt decreases, too. The time ranges from 5,016 microseconds to sweep an area 18 points square (called an 18-point em square) down to 597 microseconds for an area 5 points square. These times include a constant 5-microsecond retrace time for each scan. However, to achieve the same recording density, the slope of the crt sweeps are the same for all characters (see wave diagram below).

In the character generator, sweep amplitude is independent of point size. Since the sweep times are determined by the crt requirements, the slope of the signal increases in the Linotron tube as the point size gets smaller.

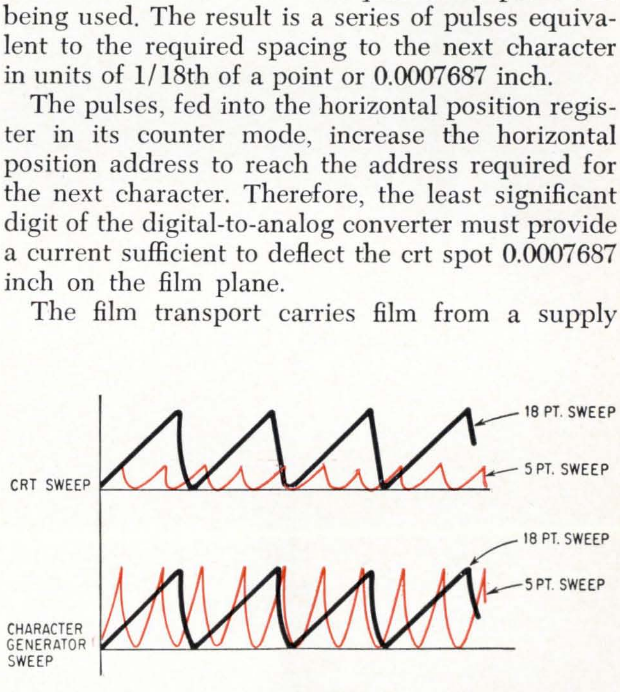
In most cases, a complete em square is not swept by the Linotron tube. Complete sweeps would cause unnecessary delays because most characters, as shown on page 121, cover only a portion of the square. For example, an i is short and narrow, a d is high, and a p descends to the bottom.

Each em square is divided into 12 sweep areas, corresponding to different groups of letters. Instructions directing the scan to the proper area are coded digitally in dots beneath each character in the grid. Typesetting speed is between 30% and 50% faster than if the entire square were scanned.

The distance each character should be set from its neighbor in a line of type is also coded beneath each character. This method of positioning in the Linotron system is called implicit positioning because no explicit commands come from the computer. Anywhere from four to 18 dots correspond to the character width. These width dots are scanned a number of times equal to the point size being used. The result is a series of pulses equivalent to the required spacing to the next character in units of 1/18th of a point or 0.0007687 inch.

The pulses, fed into the horizontal position register in its counter mode, increase the horizontal position address to reach the address required for the next character. Therefore, the least significant digit of the digital-to-analog converter must provide a current sufficient to deflect the crt spot 0.0007687 inch on the film plane.

The film transport carries film from a supply



Sweep slopes on the crt must be the same for all type sizes so phosphor brightness won't vary. Sweep slope in the Linotron tube becomes steeper as the point size gets smaller because the crt determines sweep time. The Linotron's sweep amplitude remains constant.

Quality in electronically set type

Electronics has been involved in the printing industry since the 1930's when punched tape for linotype machines was introduced. Speed and economy have been the main reasons. But it has only been within the last few years that truly impressive jumps in speed have been made in typesetting.

From rates of 20 and 40 characters per second, adequate for many newspaper operations, electronic typesetters are today pressing to speeds of 1,000 characters per second and are headed even higher [Electronics, Feb. 6, p. 34; June 13, 1966 p. 255]. Such rates are being reached by combining computers, special character-generating techniques, and high-speed film-processing systems.

However, for the printing industry, speed alone is not enough. High quality is needed, too. What does high quality in printing mean?

Resolution. Thousands of different type styles have been developed since the invention of movable type by Gutenberg in the 15th Century. They are selected for such reasons as the content of the text, the type of paper, the printing press to be used, and the taste of the publisher. Styles are differentiated by the form of the letters and, more particularly, by the fine detail associated with each letter —boldness of strokes, shape of the serifs, squareness of the corners, etc. For high quality printing the type must be reproduced with a resolution of about 10 pairs of optical lines per millimeter (500 television lines per inch).

Precision. If letters are not set accurately with respect to each other—if they bobble up and down or sideways—it impedes the natural reading process, where letters are grasped as groups forming words and phases.

One of the major functions of serifs on letters is to provide an average reference line for the eye to follow. If the letters and therefore the serifs are not placed accurately, this average reference line will be poorly defined and disjointed.

High quality is obtained when each letter is placed to an accuracy of 1 mil with respect to adjacent letters. For a typical page size, this represents a differential accuracy of 0.01%. This requirement is particularly important for small sizes of type faces where space between letters is very small.

Uniformity. Printers and typographers often refer to the "color" of a page. By this they mean the average density of type over areas large compared to a letter. On that scale, one part of a page should appear to a reader the same as another part of a page. Variations in color provided by a bold face, italics, indentation, or other techniques give emphasis or guide a reader's attention.

A typesetting machine must reproduce letters with uniform resolution, accuracy and exposure intensity at all positions on a page. This differs from the practice in tv or in conventional photography where the resolution at the corners may be substantially lower than the resolution at the center.

Flexibility. There are enormous differences in materials printed for advertising, mathematics texts, and dictionaries. Type faces and styles change and even intermix, sizes vary, and formats change. Type may be set across a page or on its side, lines may be full or left blank, they may be set tightly or widely spaced.

A machine that sets type may be very fast for pages set densely, but uneconomically slow for pages with large open spaces. A typesetter should therefore provide wide flexibility for page formats with little loss of processing speed.

cassette to the image recording plane where it's exposed and then fed into a take-up cassette. Separate automatic processors develop the film offline. Photographic paper, rather than film, is normally used for proofreading copies.

Directed by the information from the magnetic tape input, the transport pulls down film from rolls up to 12 inches wide. Film lengths for printed pages of 6, 7, 8 and 8½ inches long are programable through the computer.

To control film length, a reference hole, whose position depends on the page length desired, is punched at the top of the film as it is being exposed. At the next pull-down command, the film moves down until the hole is centered between two light sensing photocells, which are part of a servosystem, shown at the bottom of page 120. The film can be positioned to accuracies of better than ±2.5 mils, which is needed to make up over-sized pages.

The film transport must be ruggedly constructed because a full roll of 500 feet of film can weigh as much as 30 pounds. Slack loops with dancer control at the cassettes decouple the load from the drive system so that the film can be pulled down in less than one second.

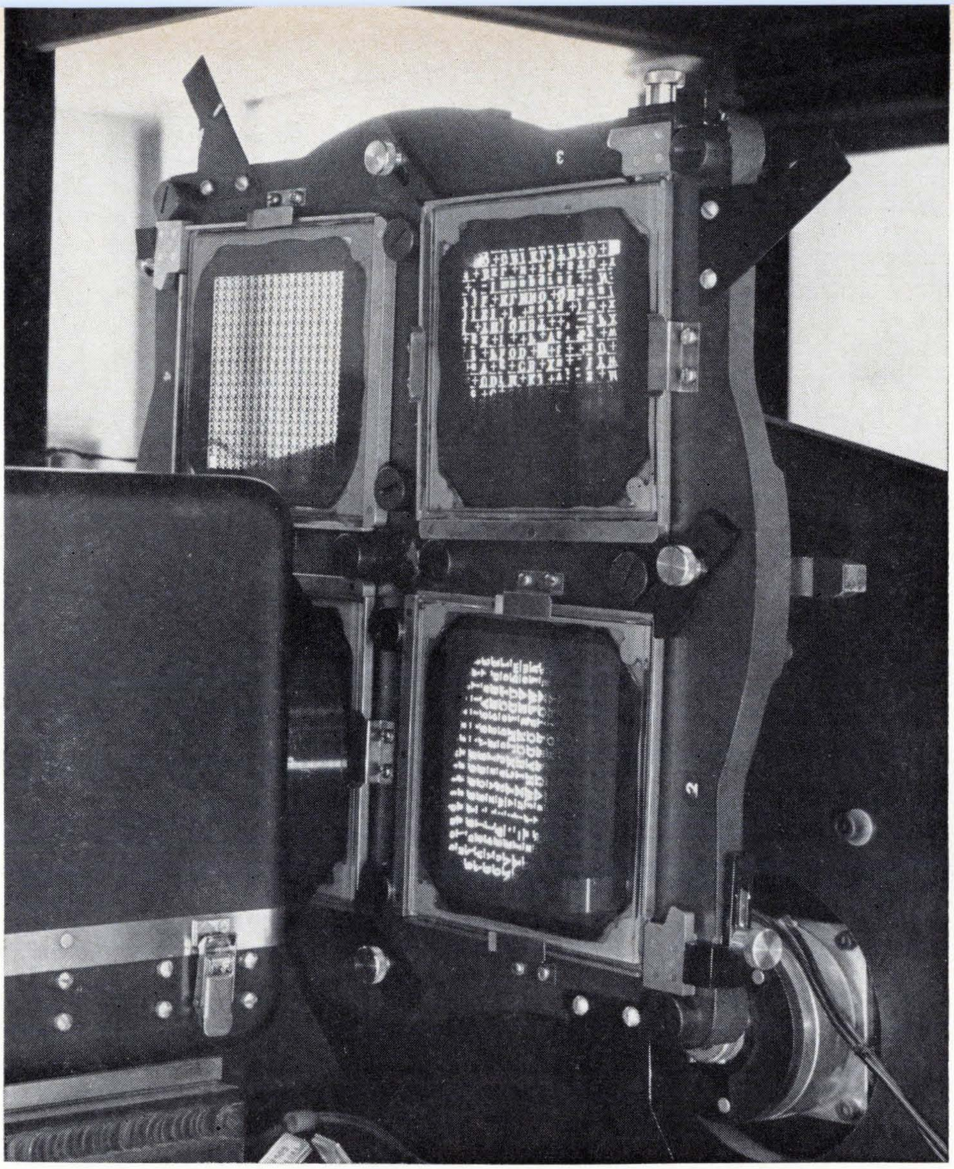
The Linotron system also has a second transport for making page proofs. This equipment developes photographic paper a page at a time in the machine.

Higher speed modes

For some requirements, proof copies for example, printing quality can be sacrificed for higher speed. The Linotron system has two higher speed modes.

In the proofing speed mode, the system operates at three to four times the normal speed. To compensate for this, the characters are scanned at about 280 scan lines per inch instead of the normal 835. The system performs all the normal operations but the letters are not as crisp as when copy is set at normal speeds.

In the other high-speed mode, the system simulates a computer's line printer and produces copy resembling that from a typewriter at speeds approaching 10,000 characters per second. It uses a special grid with small characters. They are swept with lower amplitudes of deflection current so that sweep speed is faster and retrace times are shorter. The implicit spacing logic circuits are bypassed and the characters are printed with fixed spacing increments.



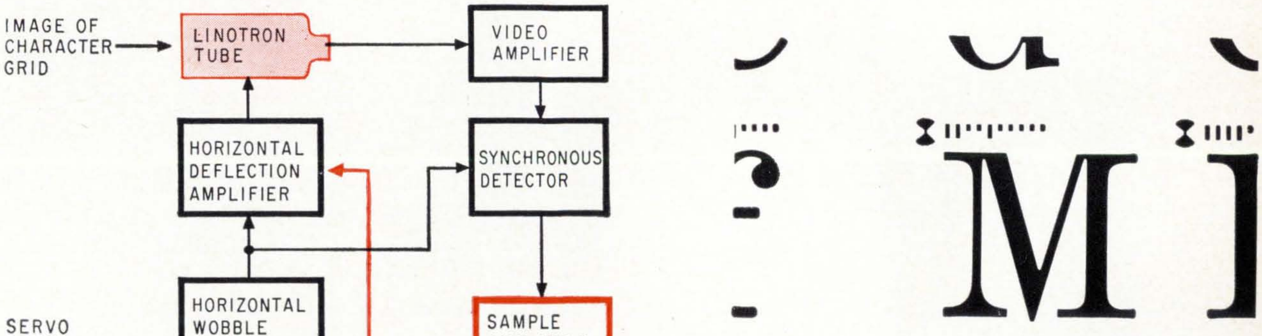
Grid changer holds four character grids, each of which can be switched into the Linotron tube in a half second.

A turn-page mode, one in which pages are composed and printed with a 90° rotation, can also be programed. This can only be done with an area composing system (see bottom of page 121).

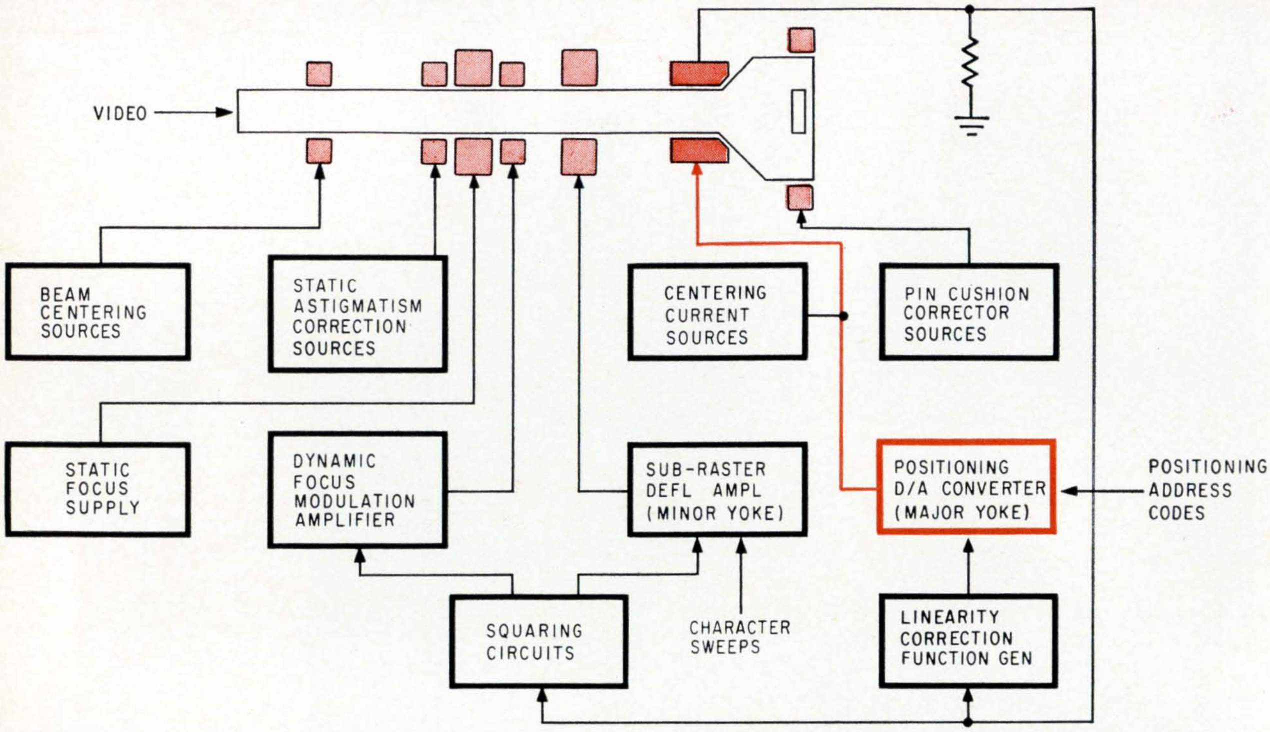
When a computer instruction calls for a turn-page mode, switches and gates within the system produce the following changes:

- X and Y positioning codes are transferred respectively to the vertical and horizontal positioning digital-to-analog converter inputs.
- Horizontal character raster deflection sweeps are transferred to the vertical deflection amplifier; the vertical sweeps are transferred to the horizontal amplifier.
- Vertical positioning yoke leads are reversed.
- Horizontal character raster deflection yoke leads are reversed.

Ruled lines may be drawn by the crt under



Servo system for horizontal axis control generates a position correction signal that locks the scan to the reference mark beneath the character. Reference and coding marks indicate how the character should be scanned and spaced.

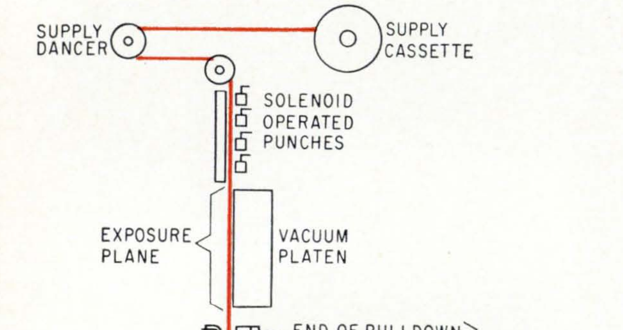


Major yoke (dark color) is controlled by the digital-to-analog converter to place the character at a selected spot on a page.

computer instruction. The computer specifies the coordinates for the origin of a line, its direction (horizontal or vertical), length and thickness. The origin of the line is set into a position register and counter which drives the digital-to-analog converter.

Upon command, the crt spot is unblanked and an oscillator is gated into the register. The oscillator pulses are also applied to a backwards counter which has been preset to a value corresponding to the length of the line. The response time of the positioning system limits the spot travel to a constant velocity as the register is advanced. When the backwards counter reaches zero, the oscillator is gated off and the crt spot is blanked.

While the spot is moving across the crt face to produce the line, an orthogonal spot wobble is applied. Line width varies with the amplitude of this wobble and spot brightness is adjusted to achieve a constant energy density on the recording film that is independent of the width of the line.



Light passing through hole punched in the film by solenoid-operated punches is sensed by servo system to determine when film has been pulled down to its selected length. Film lengths range from 6 to 8½ inches.

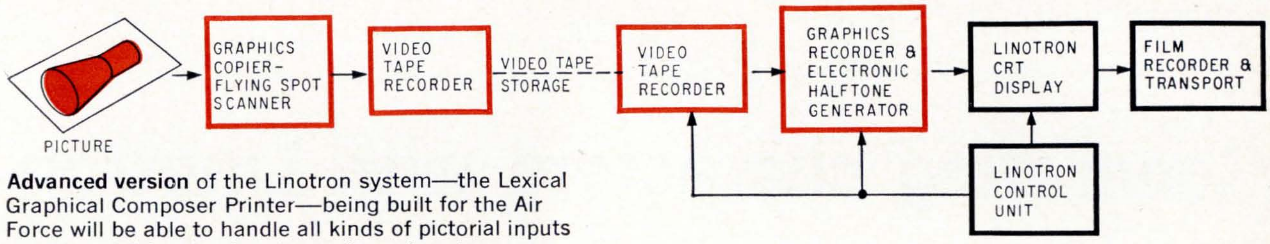
Format overlay projector

The computer is employed for drawing line formats that are not used regularly. But for formats repeated often, like column rules, the Linotron may use its format overlay projector—a digitally addressed, random access slide projector. It holds 96 slides which contain pictorial or typeset information, as well as ruled lines. The slides are 2 inches square and are magnified to page size.

A format slide is normally selected while the type is being generated on the crt. A pivoting reflecting mirror drops into position at the completion of the typesetting and flash lamps fire and expose the projected format on the recording film. Each slide can be changed in 3.5 seconds. Formats are positioned with a repeatability of about 4 mils. Most of the operating cycle for the overlay projector is shared by other system functions so that time delays are minimized.

Linotron as an X-Y plotter

The implicit positioning system of the Linotron normally positions characters within a word after the starting point of the word has been



Advanced version of the Linotron system—the Lexical Graphical Composer Printer—being built for the Air Force will be able to handle all kinds of pictorial inputs with the additional subsystems shown in color.

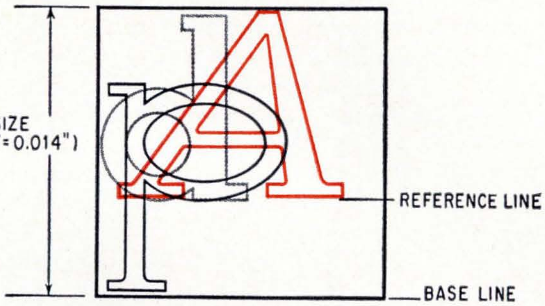
obtained from the instructions in the tape. Under such explicit control, the system behaves like an X-Y plotter.

Coordinates for the start of columns, paragraphs, lines, and words are transferred from the tape as a 5-digit binary coded decimal words. The last significant figure corresponds to 1/18th of a point.

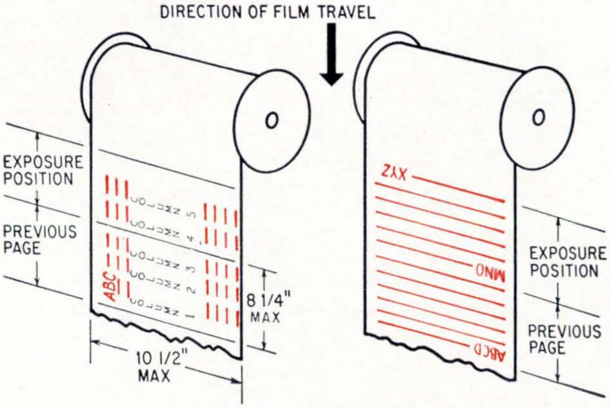
Explicit position codes preset the position registers and the blanked crt spot is moved to the required location by the deflection currents generated by the digital-to-analog converter.

When explicit positioning is used, the computer must calculate the correct coordinates for a word or line with respect to an origin on the page. Often it is more convenient for the computer to calculate an address as a differential change of location from the last position in the registers. To do this, a delta positioning capability has been designed into the control system. This allows a number to be added to the position registers so that the location of the crt spot will advance from the last position by the delta address.

Another positioning method reads the implicit positioning coding only and doesn't scan the letters. The width code is converted into spacing pulses. This allows the computer to call out spacing with fewer coded instructions.



Most characters cover only a portion of the em square for a given point size. Only the segment of the square in which the character fits is scanned.



Normal printing mode on film (left) has crt display positioned on its side. This allows wide, multi-column pages to be printed. In turn-page mode (right) pages are composed after being rotated 90° so long lists of information can be printed.

Advanced Linotron

An advanced version of the Linotron system, called the Lexical Graphical Composer Printer shown in block diagram above, is being built for the Air Force Logistics Command. In addition to all of the capabilities of the Linotron, this system will be able to process photographs. The techniques used are adaptable to a wide range of illustrations. They can even be expanded to include color separations for printing illustrations in color.

The graphic input consists of a high resolution crt flying-spot scanner which converts picture information to video signals. The video is stored on a standard broadcast video tape recorder modified to provide high resolution at slower than standard scan rates. Digital codes that describe the pictures for retrieval are also added to the tape.

The video signals corresponding to a desired picture are read out of the video tape reader into the graphics copier electronics which processes them for display on the system's crt. Precision linear sweeps are generated instead of the asynchronous jump-scan sweep used for character positioning.

The control system receives commands from the computer composition system which define the coordinates of a picture to be copied from the video tape file. As the type is set on a page, areas on the film are left blank for the pictures to be added. The blanked crt spot is moved to the space and the picture is then recorded in accurate registration with the typeset copy.

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Generating characters with Linotron

Generator tube converts printing characters into sequence of video signals that trigger high-resolution crt display

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Because Linotron photocomposition is a special kind of closed-circuit television hookup, the system requires a special camera and receiver—the Linotron character-generating tube[1] and a high-resolution cathode-ray tube.

The Linotron tube resembles an array of 256 cameras, each focusing on a particular character. The characters are projected optically onto the tube's photocathode (see cover) and a beam of electrons is emitted for each. Focused through holes in an aperture plate, the beams are dissected and converted into video signals.

A switching section blocks all but one of the signals and propels the surviving signal—chosen by the Linotron system—into an electron multiplier section, from which it is routed to the crt where the character is regenerated and projected on film.

Start with 256 beams

The character grid, projected on the photocathode by a mercury arc lamp, consists of the 16 x 16 matrix of transparent symbols on a black background. When the photocathode is struck by the images of the symbols, an energy exchange releases beams of photoelectrons that have the same cross sections as the characters. These space-modulated beams are accelerated by an electrostatic field toward the aperture plate.

The photocathode, occupying a 5-inch diameter area of the 7-inch faceplate, is of semitransparent cesium-antimony with an S-11 spectral response. It has a typical sensitivity of 40 microamps per lumen, and operates at a current density of 100 microamps per square centimeter. Neutral density filters in front of the mercury lamp control the cathode illumination. Although sensitivity slowly decreases with tube operation—limiting its life—tubes have lasted upward of 1,500 hours when the photocathodes are deposited on transparent conductive substrates.[2]

As the electron beams travel from the photocathode through the image section of the Linotron tube, they are focused and deflected at the aperture plate by three pairs of Helmholtz coils.[3] Each electron image is scanned across a 1-mil square aperture to generate video information. The apertures convert the original 256 character images into video signals. Thus, the Linotron tube is fundamentally a multiple aperture image dissector.[4]

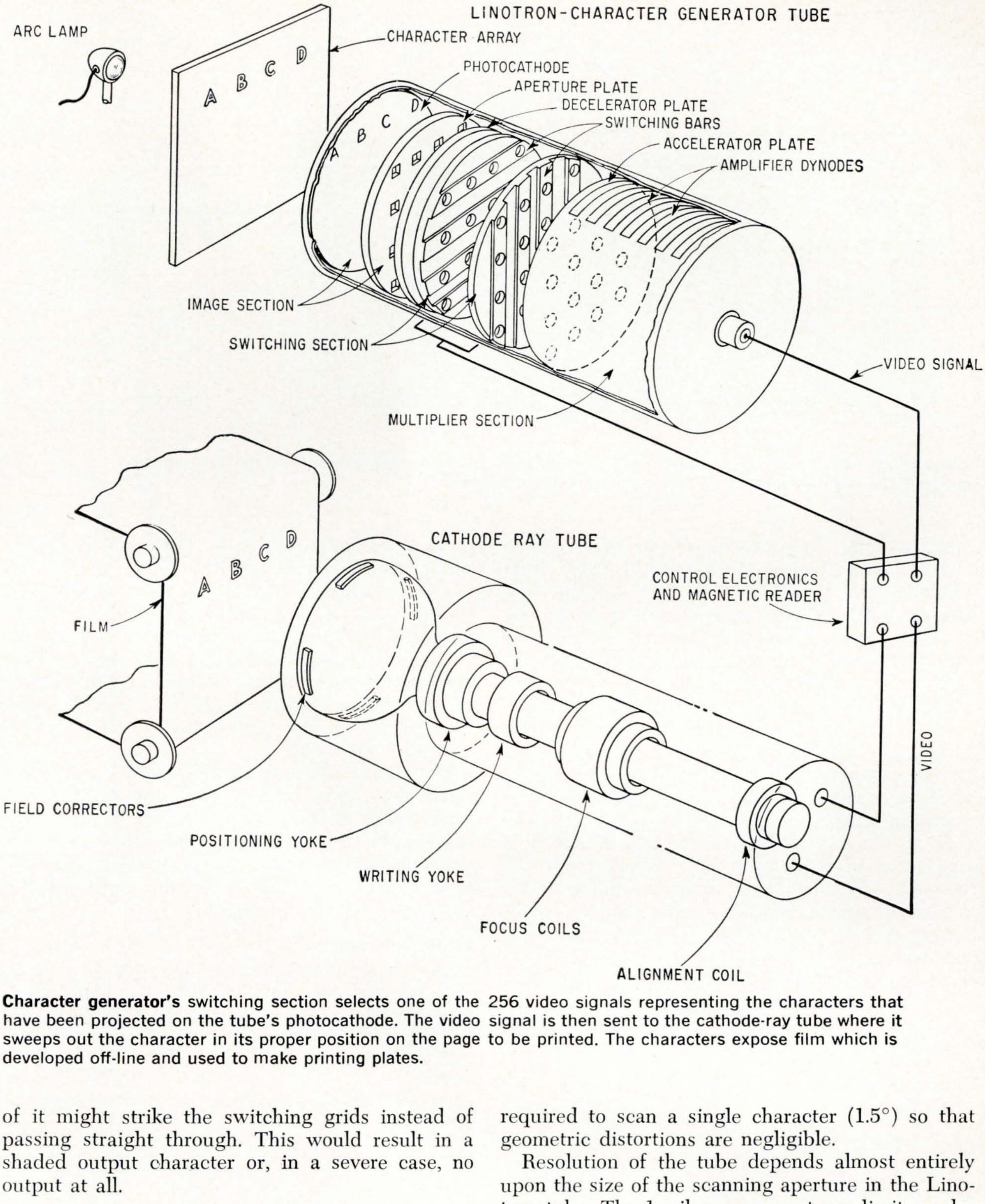
The coils make the focus and deflection fields uniform to within 0.1%. The focusing coil pair is about 20 inches in diameter, concentric with the tube and centered about the image section. It generates a 24-gauss field.

Varying horizontal and vertical deflection fields are produced by the other pairs of coils. The sweep fields of the deflection coils are generated by currents supplied by high-power deflection amplifiers. Linearity and stability of these amplifiers are approximately 0.1%, and they have a 1-megahertz signal bandwidth. The highest deflection-signal frequency, used for the smallest characters, is approximately 125 kilohertz. Total current in the horizontal deflection coils is 16 amperes and coil inductance is 10 microhenrys.

A mutually orthogonal arrangement of the coil pairs readily eliminates stray fields. The earth's field, for example, can be canceled simply by creating opposing fields which neutralizes its effect.

Both the magnetic and electrostatic fields must be uniform in the image section. Distorted electrostatic fields can cause the beams coming from the photocathode to be out of focus, especially beams that aren't close to the axis of the tube, shown in the schematic at the bottom of page 125.

An off-axis beam would pass through the aperture plate incorrectly, causing the crt to reproduce the character in a shifted position. In the switching section, the beam would be further effected. Part



Character generator's switching section selects one of the 256 video signals representing the characters that have been projected on the tube's photocathode. The video signal is then sent to the cathode-ray tube where it sweeps out the character in its proper position on the page to be printed. The characters expose film which is developed off-line and used to make printing plates.

of it might strike the switching grids instead of passing straight through. This would result in a shaded output character or, in a severe case, no output at all.

Image at the aperture

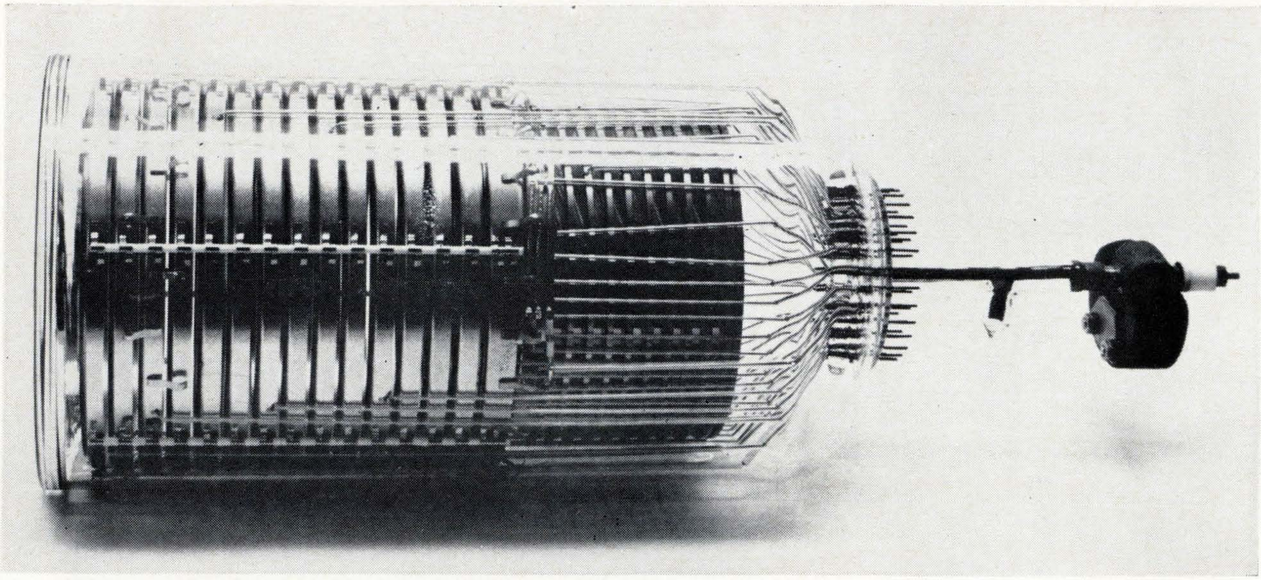
Each symbol of the character grid has its own aperture, a hole 1 mil square, in the aperture plate. The apertures dissect the images into incremental video signals with a 5-Mhz bandwith, when the beam scans them.

Although each of the 256 high resolution image dissector scanning tubes within the Linotron tube is associated with a single character, all are scanned in parallel. Scanning angle is only that required to scan a single character (1.5°) so that geometric distortions are negligible.

Resolution of the tube depends almost entirely upon the size of the scanning aperture in the Linotron tube. The 1-mil-square apertures limit resolution to 20 line-pairs per millimeter. Higher resolution is not required, but could easily be obtained by reducing the aperture size. Tradeoff for this would be a reduction in the output current and a decrease in the signal-to-noise ratio.

Switching section action

The switching section—which allows only one of the 256 video signals to be accelerated toward the multiplier section where it is amplified before



Linotron tube has 65 leads that control character selection and signal amplification. An ion getter pump, right, maintains a hard vacuum in the 13½-inch-long glass tube.

going on the crt—consists of 16 vertical and 16 horizontal stainless steel bars. Insulated from each other and placed between two field plates, the bars are 100 mils wide and 50 mils thick. In the bars are holes 60 mils in diameter that line up with the holes in the field plates and apertures, as in the partial schematic at the top of page 127.

The first field plate, directly behind the apertures, decelerates the electrons so that they pass through the section slowly and are easier to control. The second plate is held at the same potential as the first, creating a field-free region within the switching section.

The beam representing the desired character is accelerated by applying a high voltage, 100 volts compared with 30 volts on the photocathode, to one vertical and one horizontal switching bar. The other bars are kept at zero voltage. In effect, this opens only one of the holes in the switching section—at the crossing point of the energized bars—and closes the others, while propelling the selected signal through the second field plate and into the multiplier section of the tube.

Electron multiplier

A 10-stage electron multiplier amplifies the small currents obtained from the photocathode. The intensity of light falling on the photocathode and the voltages on the multiplier chain are adjusted so that the anode current at the output is 25 microamperes.

The multiplier has a venetian blind structure which is less sensitive to magnetic fields than other types.

Another advantage of this structure is that the vanes of each dynode can be spaced to match the period of the aperture rows. Each input signal enters the common multiplier at a different point and travels to the anode through its own section.

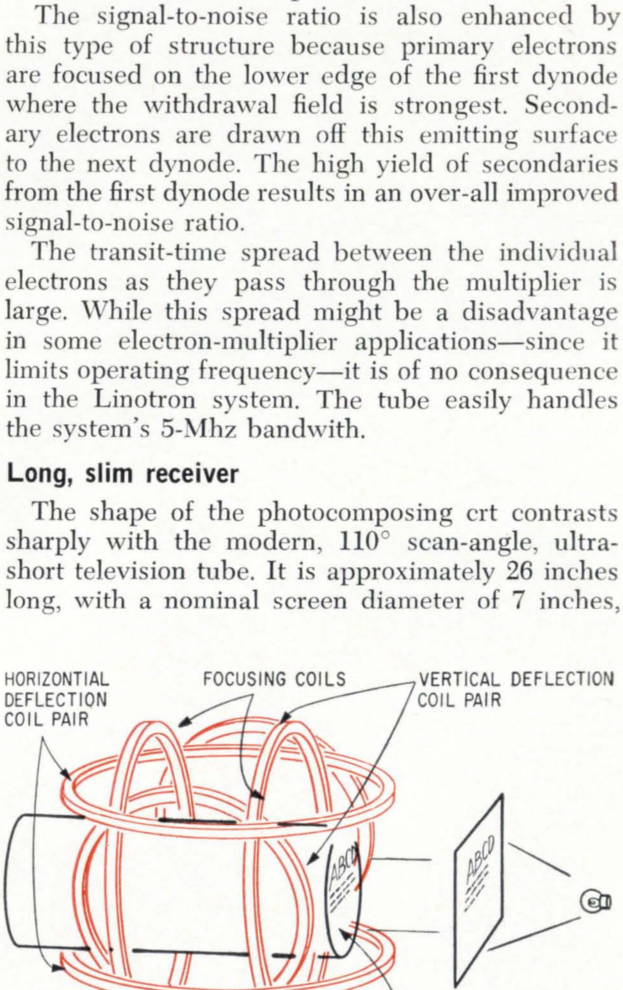
A partitioned effect is created. Each partition is identical, minimizing the variation in anode current from different apertures.

The signal-to-noise ratio is also enhanced by this type of structure because primary electrons are focused on the lower edge of the first dynode where the withdrawal field is strongest. Secondary electrons are drawn off this emitting surface to the next dynode. The high yield of secondaries from the first dynode results in an over-all improved signal-to-noise ratio.

The transit-time spread between the individual electrons as they pass through the multiplier is large. While this spread might be a disadvantage in some electron-multiplier applications—since it limits operating frequency—it is of no consequence in the Linotron system. The tube easily handles the system's 5-Mhz bandwith.

Long, slim receiver

The shape of the photocomposing crt contrasts sharply with the modern, 110° scan-angle, ultrashort television tube. It is approximately 26 inches long, with a nominal screen diameter of 7 inches,



Helmholtz coils over the image section focus the beams at the aperture plate and scan them across the aperture holes.

shown at the bottom of page 127. An area with a diameter of only about 6 inches is used to display the information, which reduces the scanning angle to approximately 40°.

This smaller angle helps to keep the spot size of the beam uniform. The image on the screen is magnified 2.3 times, to a rectangular area with a 14-inch diagonal, before it is projected on the printing film.

The single-beam, high-resolution electron gun is of tetrode design and has an oxide-coated cathode. Angular spread is approximately 0.03 radians. Anode voltage is typically 30,000 v and can go as high as 45,000 v. The gun is fabricated without the limiting apertures often used to reduce the diameter of the electron beam. This means that the beam current can be high.

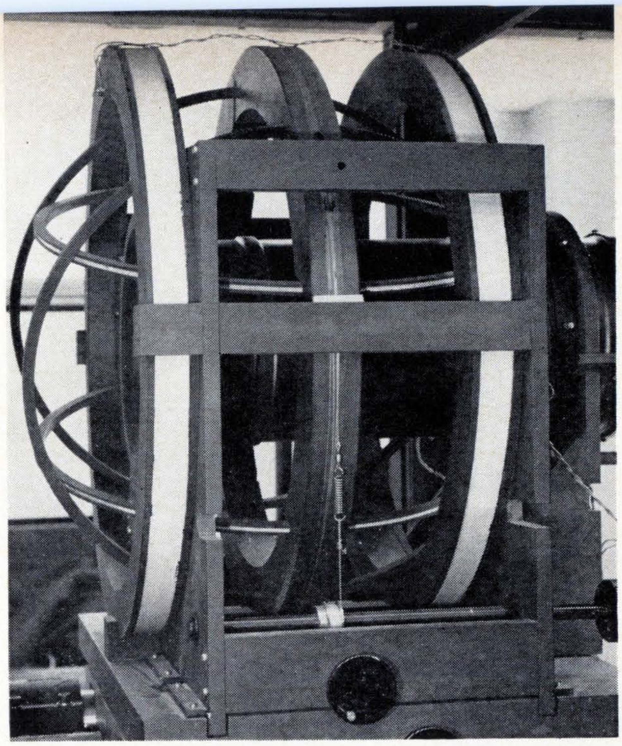
The beam diameter is ⅓ in. at the main focus coil. Yet at a beam current of 20 microamperes, the resolution is 24 line pairs per millimeter—a better resolution than the eye can distinguish when the film is inspected.

Extra focusing

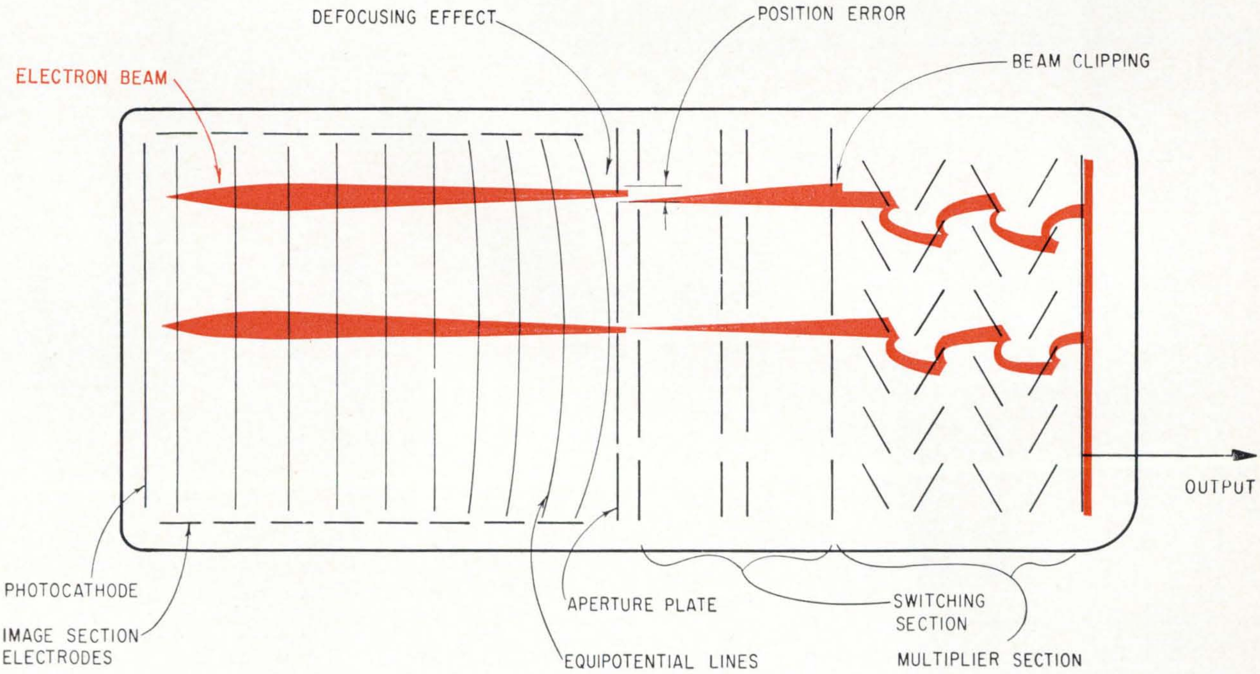
Dynamic refocusing keeps the spot size at 1.5 mils in diameter any place on the faceplate, although the beam diameter is large as it passes through the deflection coils.

The main focus coil is 2 inches in diameter. Its large inductance makes it unsuitable for the rapid changes of focus needed to position characters at different locations on the tube's faceplate. The faceplate is flat, rather than curved so the image can be projected on the flat film. Thus, beam length changes with each character location. Without dynamic focusing, spot size would not be constant. A dynamic focus coil, driven from high-speed squaring circuits, compensates for this change in the path length of the deflected beam.

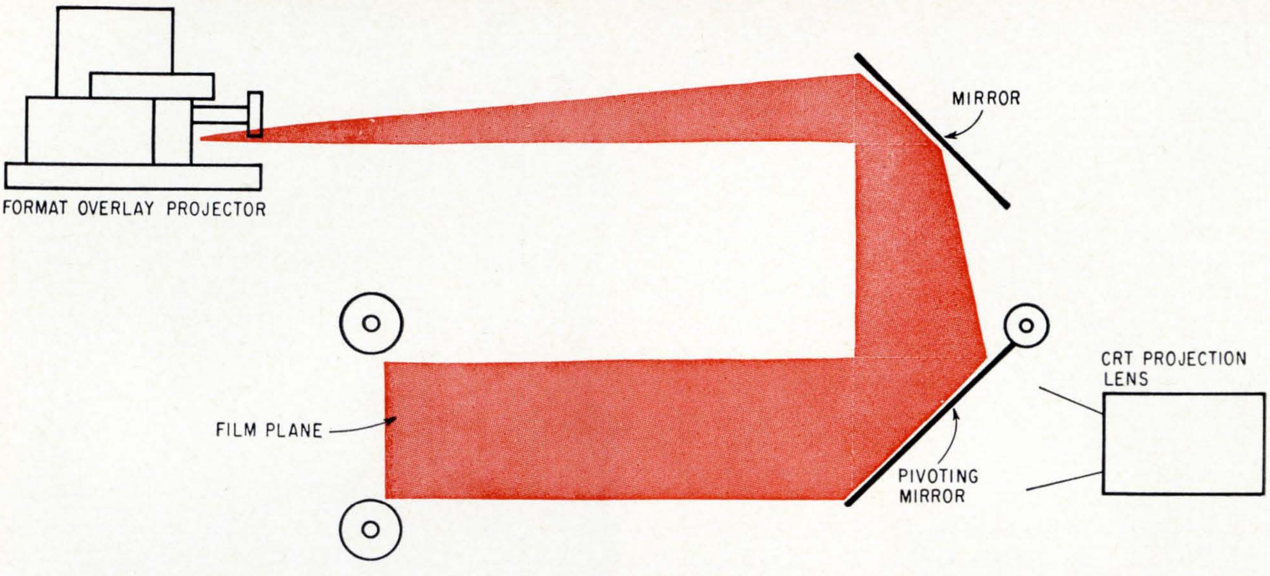
The coil is built in a low-loss ferrite case with an air gap close to the major focus coil. Sharing the major focus gap, and therefore its core material, can lead to serious problems of hysteresis and eddy currents when the focus modulation



Large Helmholtz coils at the ends of the image section are the focusing coils. Between them is support ring. Two smaller pairs of coils are for vertical and horizontal deflection.



A uniform electrostatic field in the image section and careful focusing result in a beam passing straight through the aperture plate and the switching and multiplier sections (the beam at the center). If the field were not uniform, an off-axis beam (the upper beam) would not be focused exactly at its aperature. The result would be characters printed out of focus or with nonuniform intensities.



Standard overlays may be projected onto film after completed page has been composed. Pivoting mirror drops into place so that it reflects slide image from format overlay projector.

changes rapidly. Hence, both the major and minor focus current supplies must be highly regulated and stable.

This auxiliary coil has negligible residual magnetism so that central focus is regained when the dynamic coil current is removed. Astigmatism isn't introduced during refocusing. However, some may occur because of lack of circular symmetry in the main focusing field. This is corrected by a magnetic quadripole astigmator that acts as a cylindrical lens. Now perfectly circular, the undeflected beam is directed along the axis of the tube by an alignment coil.

Character positioning

The major deflection yoke moves the electron beam into the position on the crt faceplate at which the character is to be written and holds the beam there. This position is selected by the Linotron system. The character is written by the minor deflection yoke that scans the electron beam at high speed over the small area required to display the character.

Character grid has letters and numbers in roman, italics and bold face.

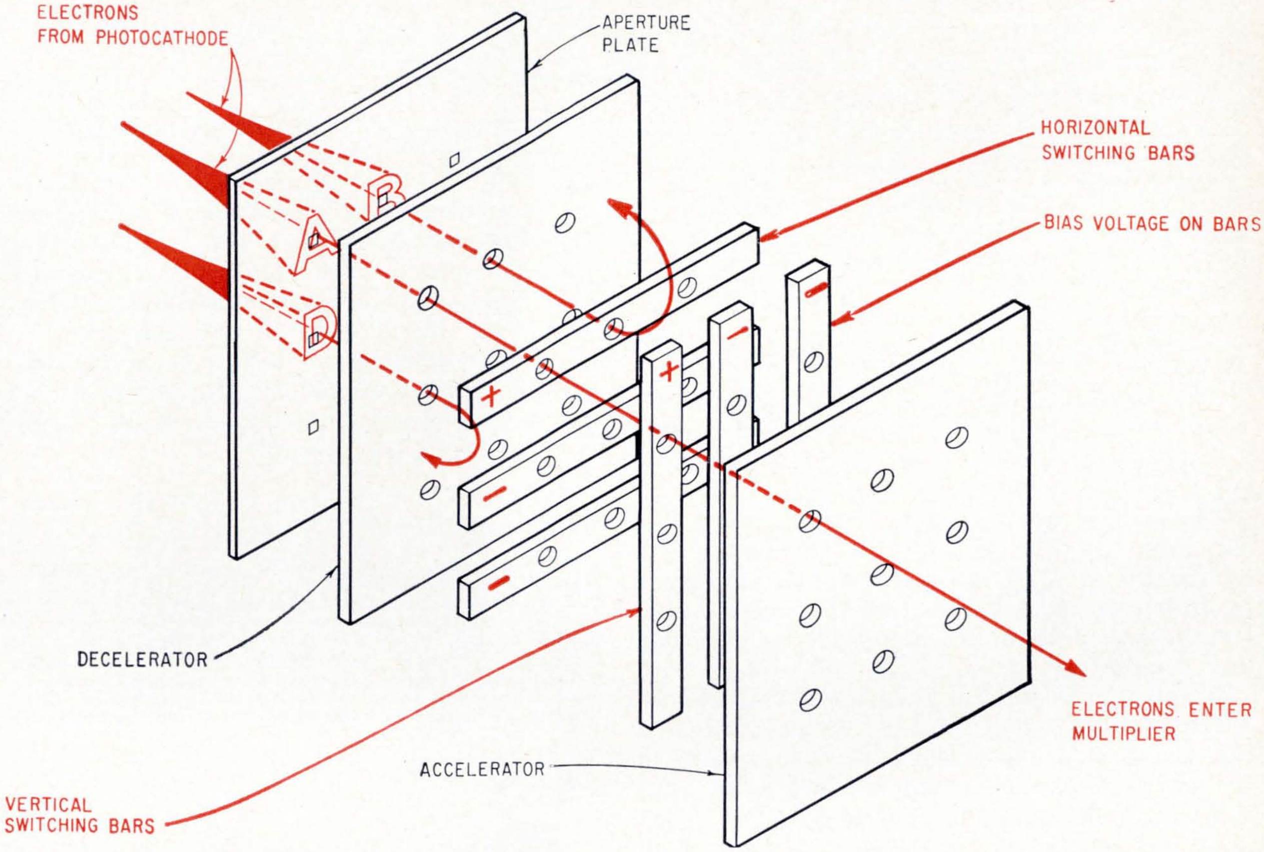
Because the deflecting fields are so well balanced there is no astigmatism, the most important spot distortion to avoid. Only a small amount of non-orthogonality (less than 0.05°) is acceptable. This is maintained by inserting a single layer subyoke inside the main yoke and in series with one deflection axis. This component is rotated until nonorthogonality is reduced to a level set only by the accuracy of the instruments being used to measure the defect.

The character-writing minor yoke has only a few microhenrys inductance. The deflection angles are extremely small and the minor yoke doesn't distort the focused spot. Orthogonality of the deflection axes is the same as for the major yoke, within 0.05°.

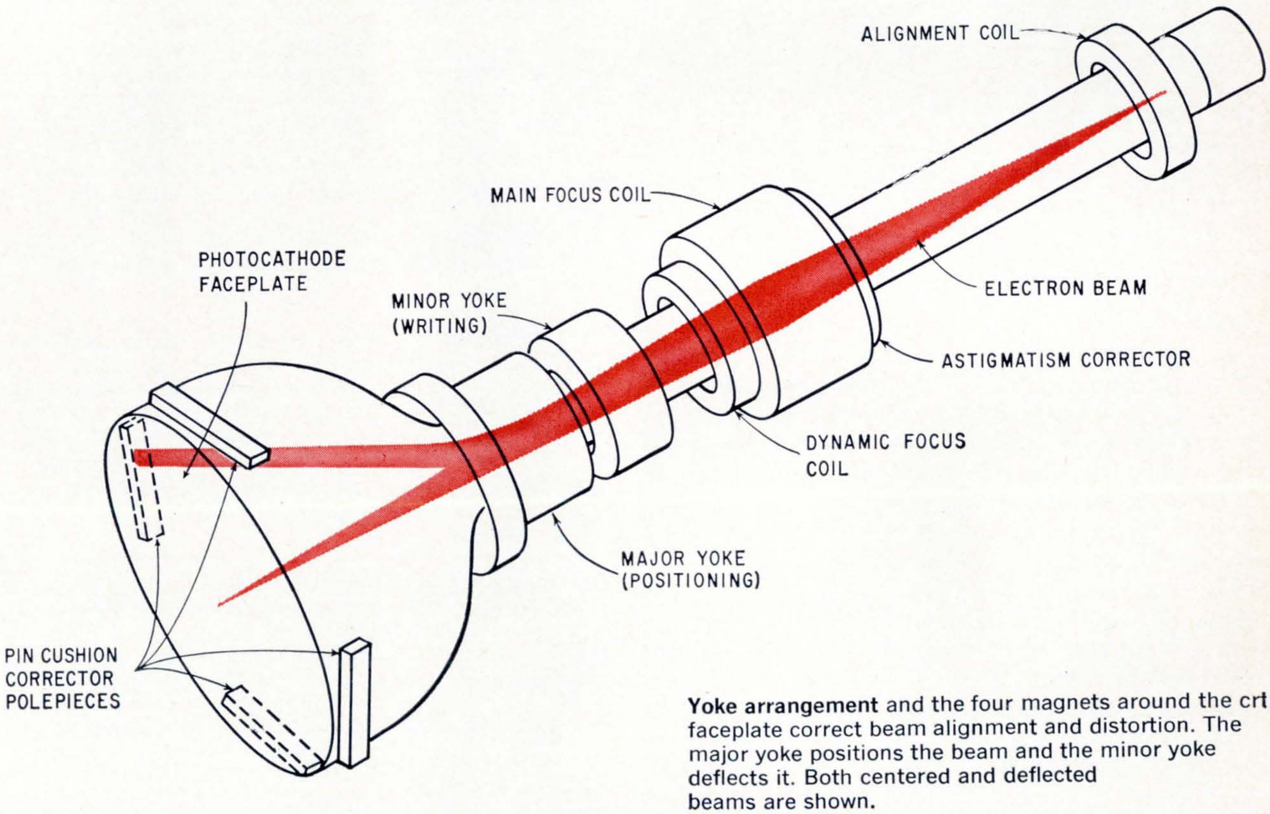
The minor yoke is close behind the major yoke to keep the off-axis distance of the electron beam minimal as it enters the major deflecting fields. Vertical and horizontal deflection axes of the minor yoke accurately parallel the corresponding deflection axes of the major yoke. This eliminates—without shielding—cross coupling between the two yokes and preserves the quality of the page of print.

Corrected positions

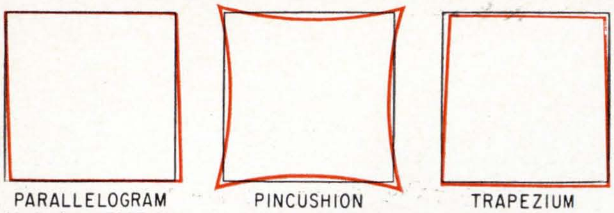
However, the sweep signals for the subraster generated by the minor yoke must be corrected so character size is independent of location—another requirement imposed by the flat faceplate. Both the horizontal and vertical subraster dimensions depend on horizontal and vertical location. Without correction the same angle would produce a longer beam scan near the edge of the tube than in



High voltage applied to one horizontal and one vertical switching bar select a beam carrying the video signal for a single character.



Yoke arrangement and the four magnets around the crt faceplate correct beam alignment and distortion. The major yoke positions the beam and the minor yoke deflects it. Both centered and deflected beams are shown.



PARALLELOGRAM (SKEW) DISTORTION — PINCUSHION DISTORTION — TRAPEZIUM DISTORTION

Correction of these raster faults on the crt yields displays with edges straight to within 1 mil over a 5-in-long display. Opposite sides are parallel to 2 mils.

the center and the character would become shorter and wider.

The correction is a function of $K_1H^2 - K_2V^2$, where H and V are the horizontal and vertical voltages, respectively, K_1 and K_2 are constants of the deflection systems.

The squared terms are derived from the function generators used to provide focus modulation and are added into the sweep generator amplitude control reference voltages. Deflection of the electron beam is uniform to within 0.1% for deflection angles of 20°.

Residual magnetism in the major deflection yoke is low enough so that spot displacement is only a fraction of its diameter when the beam returns to the undeflected position from full deflection.

The ferromagnetic material also permits very rapid and precise deflection of the spot between all positions on the tube face.

Raster geometry

Four separate magnetic pole pieces placed close to the phosphor plane of the crt correct pin cushion distortion, the most eye-jarring defect in a crt raster. This distortion is particularly noticeable where an uncorrected raster appears to have bowed sides. In the crt, sides of the raster are straightened to within 1 mil; corners are also located to the same accuracy.

Usually, a pin cushion corrector is close to the deflection yoke on the faceplate side where it requires less power and doesn't make the faceplate end of the tube bigger. This couldn't be done here because the correction and yoke fields would interact, distorting the deflected spot.

Parallelogram distortion is eliminated by making sure the horizontal and vertical deflections are orthogonal. Other faults, like trapezium distortion, are dealt with by aligning precisely the correction, focus, and deflection components of the tube. The undeflected beam must, for example, land orthogonally on the phosphor screen. Adequate magnetic shielding prevents stray fields from influencing the position of the beam.

A number of the currents and voltages also must be extremely stable. Possibly the most important are the alignment coil currents and the final anode voltage. Upon these depend the location of the electron beam with respect to the focus coil, main deflection yoke, and pin cushion corrector. An incorrectly positioned beam may lead to only a slight loss of resolution but the effect upon raster shape, when the accuracy must be within 0.01%, could be disastrous.

Bright display

The faceplate and luminescent phosphor plane of the crt must be unusually uniform and blemish-free. Otherwise, the slightest fault would show up as broken or distorted characters. A fine-grain P24 phosphor (ZnO:Zn) is used. This material's bright emission spectrum fits well with high contrast film. The phosphor is also rugged and withstands high peak current densities and ages slowly. It emits more light than other fast decay phosphors such as a P16 ($CaMgSiO_3$:Ce), for example. Variation in light output due to granularity, or phosphor noise, is less than 2% rms.

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